

# The Concept of an Emergent Cosmographic Vacuum

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## Abstract

The argument for an “*Emergent Cosmographic Vacuum*” state which generates fermion and weak boson masses is outlined. Its limitations and its consequences are discussed. Predictions for LHC are presented.

The *hierarchy problem* in particle physics is used as a guidance for concepts beyond standard model physics [1]. The argumentation often presented wrongly presumes a separation of particle physics and cosmology. Without such a separation there is no need to directly connect masses to GUT scale physics as a manageable scale is available from the cosmological constant.

Of course this just changes the context as cosmology actually contains a worse hierarchy problem in its vacuum structure [2]: The cosmological constant is taken to correspond to the vacuum energy density caused by a condensate [3, 4]. The properties of the condensate have somehow to reflect a Grand Unification scale of the interactions when it was formed (i.e. above  $10^{15}$  GeV), whereas the flatness of the universe requires a non-vanishing but tiny cosmological constant (about 3 meV).

The size of the gap rises a serious question. It is possible that a solution of a type envisioned for the particle physics hierarchy problem [5, 6] will eventually be available.

Here we adhere to an opposite opinion and consider it impossible to connect such scales. A Lagrangian with Grand Unification scale mass terms can then not contain minima in its effective potential involving such tiny scales. Of course, condensates contain compensating energy terms, but without a new scale true field theoretical minima have to stay on a GUT scale or they have to vanish<sup>1</sup>.

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<sup>1</sup>Studying the cosmological evolution similar ideas involving a time-dependent vacuum state [7, 8, 9] were considered. However, based on the scale argument we here stick to the hypothesis that the vanishing of the energy density of the true minimal state does not depend on the time. An undisturbed vanishing vacuum energy is also postulated by [10, 11]. A somewhat similar analogy to semiconductors is used in their argumentation.

The observed non-vanishing cosmological constant then means that a true minimal vacuum state is not reached. The spontaneous symmetry breaking has to be replaced by an evolving process which is not finished. The present condensate has to be quite close to the final minimum. It has to be constant over cosmic distances and it has to sufficiently decouple from the visible world.

What could be the history of such a physical vacuum state? In a chaotic initial phase of GUT scale temperature tidily bound composite states are formed with considerable statistical fluctuations. As these states are 'massless' on a GUT scale they or weakly bound configurations of them can reduce their remaining energy by geometrically extending. In this way they also more and more decouple from the hotter rest. Eventually structures are formed in a quantum mechanical process which are constant and coherent on a sizable cosmic scale.

The advantage of this picture is that it requires no new scale. States without scale are called "gap-less" [10]. Without such a scale the evolution of the dark energy in a comoving cell  $\epsilon_{\text{vac.}}$  has to be something like:

$$\partial\epsilon_{\text{vac.}}/\partial(\epsilon_{\text{vac.}}t) = -\kappa\epsilon_{\text{vac.}}$$

where  $\kappa$  is a dimensionless decay constant and  $t$  the time. It leads to a simple linear decrease. The absence of the usual exponential decrease has the consequence that the age of the universe is no longer practically decoupling and irrelevant. The expansion of the universe is not linear in time. In the above equation the time  $t$  has to be replaced by the expansion parameter  $a$ , i.e.  $\epsilon_{\text{vac.}} \propto \frac{1}{a}$ . The expansion constant is thought to be  $a \sim \sqrt{t}$  initially and  $a \sim t^{2/3}$  later on [15]. The problematic ratio

$$\frac{\epsilon_{\text{GUT}}}{\epsilon_{\text{vacuum}}(t_0)} = 10^{27}$$

can then be obtained from the age of universe

$$a \propto t_0^{0.5} = (5 \cdot 10^{46} \frac{1}{M_{\text{GUT}}})^{1/2} \text{ resp. } (5 \cdot 10^{46} \frac{1}{M_{\text{GUT}}})^{2/3}$$

to the accuracy of the consideration. The ratio of grand unification and present vacuum scale just connects to the age  $t_0$  as an outside quantity.

It allows to understand the cosmological hierarchy problem on a conceptual level. Of course the argumentation is rather vague and there is not even a cosmological toy model. However, this is an intrinsic problem of "Emergent" phenomena. Without the constraint that the physical vacuum is at an actual minimum there is too much freedom and it is hopeless to find a realistic ab initio description. Actually this is quite typical for most condensed matter in solid state physics where the term Emergent Phenomena was coined for such objects [13, 14]<sup>2</sup>.

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<sup>2</sup>To stress the new situation the term "Cosmographic" might be useful [16, 17]. As in *geography* many properties of the *Cosmographic Vacuum* are dependent on a chaotic history and seemingly accidental. The name of Cosmography was first used by Weinberg [18].

Of course this choice is extremely ugly from a model building point of view. It actually leads to a murky situation: *The vacuum is largely unpredictable but predictions are necessary for the way science proceeds.*

In this hopeless situation a tergiversate observation offers to a certain degree an escape. The standard model contains many aspects with broken symmetries. It is appropriate to assume that many of them just reflect asymmetries in the accidental vacuum and that the true fundamental physics actually is symmetric. If one accepts this esthetic point it is actually possible to come to a number of predictions. The basic ignorance of the vacuum keeps them on qualitative levels.

One important outcome of this argument is that the present physical *vacuum is not unique*. This has an immediate consequence. Gravity surely can compress the non unique vacuum condensate. The distinction between compressed dark energy and dark matter is blurred. A suitable compressibility can eliminate the need of dark matter altogether and lead to *an effective MoND description* [19, 20, 21]. This natural, effective theory does not require to touch fundamental laws and it obviously has no problem with relativistic invariance. The offset between the baryonic and dark matter component seen after galaxy collisions [22] constitutes no problem as it takes cosmic times to rearrange the dark energy.

Another important outcome of the argument is that the not unique vacuum can act as a *reservoir*. It is unsatisfactory to attribute the matter-antimatter asymmetry to the initial condition of the universe. It is widely agreed [23] that no suitable, sufficiently strong asymmetry generating process could be identified. The Cosmographic Vacuum offers a simple way to abolish the asymmetry as the vacuum can just contain the matching antimatter. Nothing forbids it to contain spin- and chargeless states like Cooper pairs of two antineutrons<sup>3</sup>. Known condensation often involves replication processes which naturally allow to amplify tiny asymmetries over many decades. In this way initial statistical fluctuation can be magnified to extend over cosmic regions in the universe. A reasonable concept is that the antibaryonic condensate is then seed to a somewhat less tidily bound mesonic cloud and to a gluonic component known from the chiral symmetry breaking.

As these extremely extended fermionic states are practically massless their fermi repulsion will dominate. They provide an antigravitating contribution in the cosmological expansion<sup>4</sup>.

The antimatter vacuum was introduced for reasons given above. It also affects other symmetries. Whether the resulting consequences are consistent offers a non trivial cross check.

The vacuum state fixes the Lorentz system. Its tiny energy scale leads to a huge geometrical extension and the momenta exchanged with the vacuum have to

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<sup>3</sup>Even in the outside world roughly 1% of the baryons are in neutron condensates (in neutron stars).

<sup>4</sup>Models in which the pressure in the cosmological equation is a function of the density were considered in [24].

be practically zero. Such interactions are described with scalar, first order terms of a low energy effective theory [25]. With such terms the Lorentz system of the (very light) vacuum state cannot be determined. This leads to the observed *Lorentz invariance* in the outside world [12].

All masses have to arise from interaction with the vacuum. Their effective couplings should be rather similar. The mass differences originate in distinct densities. The excessive number of mass parameters is unacceptable for fundamental physics. Here the problem is solved by appropriately attributing them to the Emergent vacuum. The concept then explains Hawking’s postulate [30], stating that ‘the various *mass matrices cannot be determined from first principles*’. The postulate doesn’t preclude that certain regularities might be identified and eventually explained [31, 32].

How do fermions obtain their masses? The relevant interaction  $q_i + (\bar{q}_i)_V \rightarrow q_j + (\bar{q}_j)_V$  with the vacuum ( $V$ ) in the lowest perturbative order is shown in Figure 1. Relying on the Fierz transformation we find that it is dominated for the low momentum limit by a scalar part of the fermion-exchange contribution between the visible world and the vacuum.

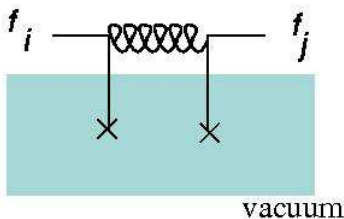


Figure 1: A process responsible for the fermion mass terms

We assume that such a flavor-dependent contribution stays important if higher orders in the perturbative expansion are included. The matrix elements depend on the corresponding fermion densities and on the properties of their binding, as interactions with fermions involves a replacement process [27, 28]. Multi-quark baryonic states should be more strongly bound than the mesonic states [29] and fermion masses should be dominated by the less tidily bound mesonic contribution. In this way the required dominance of the  $t\bar{t}$  contribution is not disturbed by the presence of light quark antineutrinos.

The “*flavor half-conservation*” is a serious problem in the conventional view. Here the flavor of  $q_i$  has not to equal the flavor of  $q_j$ . In this way *flavors conservation* can be restored and the apparent flavor changes in the visible world can be attributed to a reservoir effect of the vacuum. As the vacuum has to stay electrically neutral the mass matrix decomposes in four  $3 \times 3$  matrices which can

be diagonalized and the CKM matrix can be obtained in the usual way. As there are no new energy scales affecting the diagonalization one finds flavor changing neutral currents are suppressed as in the one Higgs model on a tree level. If the coherent vacuum state is properly included unitarity relations are not affected.

Our vacuum state is obviously not symmetric under  $CP$  and  $CPT$  symmetry. This allows to restore these symmetries for fundamental physics. Without any assumptions about discrete symmetries it is then easy to see why  $CPT$  is conserved separately in our outside world and why  $CP$  not.

In the low momentum limit a vacuum ( $V$ ) interaction of  $q_i + (\bar{q}_i)_V \rightarrow q_j + (\bar{q}_j)_V$  will equal  $\bar{q}_j + (\bar{q}_i)_V \rightarrow \bar{q}_i + (\bar{q}_j)_V$ . In consequence the asymmetry of the vacuum cannot be seen and  $CPT$  is separately conserved in the outside world.

On the other hand the  $(\bar{q}_i)_V/(q_i)_V$  asymmetry in the vacuum will differentiate between  $q_i + (\bar{q}_i)_V \rightarrow q_j + (\bar{q}_j)_V$  and  $\bar{q}_i + (q_i)_V \rightarrow \bar{q}_j + (q_j)_V$ . In consequence  $CP$  appears as not conserved<sup>5</sup>.

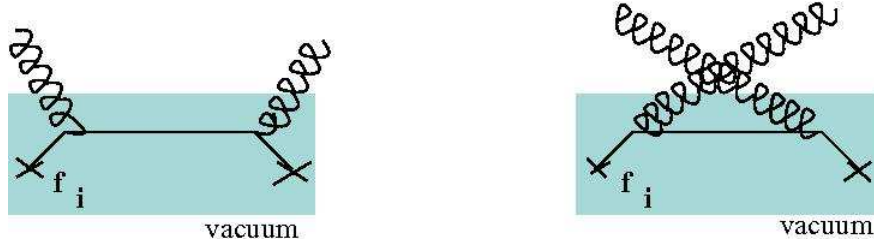


Figure 2: A process responsible for the vector boson mass terms

How do weak vector bosons obtain their masses? Relevant is a Compton scattering process like  $W_\mu + (\{\bar{q} \cdots\}_i)_V \rightarrow W_\nu + (\{\bar{q} \cdots\}_j)_V$  shown in Figure 2. In the low momentum limit the interaction with gauge bosons essentially measures the squared charges of the vacuum content.

Gluonic and Technicolor [26] like mesonic condensates states are  $U(1)_B$  neutral and cannot contribute to a  $m_B$ -mass term. The appearance of baryonic or antibaryonic states in the vacuum provides a  $U(1)_B$  charge. It creates a  $(B, W_0)$  mass matrix, which diagonalizes in the usual way. The symmetry of this matrix and the electrical neutrality of the vacuum ensures  $m_\gamma = 0$ . The consistency has again to be taken as a non-trivial success of the concept.

*Can one make predictions for LHC?* Three “vacuum” fluctuations in bosonic densities are of course needed for the third component of the weak vector bosons.

<sup>5</sup>Consider the  $(K_0, \bar{K}_0)$  system as an example. We assume that such a pair was produced and that the  $K_0$  remnant is observed in the interference region. As postulated above there are more  $\bar{d}$  anti-quarks than  $d$  quarks in the vacuum. The amplitude, in which a pair of  $d$  quarks is effectively deposited in the vacuum during a  $K_0 \rightarrow \bar{K}_0$  transition and then taken back later on during two  $\bar{K}_0$  decays, obtains a different phase as that of conjugate case of a pair of  $\bar{d}$  anti-quarks deposited for the corresponding time. This changing phase exactly corresponds to what is experimentally observed in  $CP$  violation.

In principle such phononic excitations can be built with arbitrary  $f_i \bar{f}_j$ -pairs and there should be plenty of such techni-pion-like states presumably within an order of magnitude of the Weak Boson mass.

It is not difficult to distinguish these bosons from the usual Higgs boson [33] as they couple to the fermions in a completely distinct way: They are private “Higgs” particles [34], which couple (except for the Weak Bosons) exactly to one fermion type. There is no flavor dependence in the coupling strength of various techni-pion like states as masses were differentiated just by distinct densities.

If they exist  $\nu\bar{\nu}$  “Higgs”-bosons might have the lowest mass. Such bosons would predominantly decay into neutrinos and its signature would be that of invisible Higgs bosons [36] with three distinct mass values.

The light-fermion “Higgs”-bosons are not suppressed by tiny coupling constants. If the energy is available they will be easy to observe. The large-transverse-momentum-jet production at Fermilab limits the mass of the light-fermion “Higgs”-bosons to an energy above 1 TeV [37] and LHC will extend this limit.

The Emergent-Cosmographical-Vacuum concept is not a beautiful scenario. If correct the degree to which theory can be developed is quite limited and we can forget the dream about ever reaching the *‘Theory of Everything’*. However things fit together in a surprising way on a qualitative level and the assumptions of the Cosmographical-Vacuum concept are not unpersuasive. Private Higgs particles with flavor independent coupling constant would be an indication that an emergent scenario would be *nature’s choice*.

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